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MODELING OF HYDRAULIC HOSE PATHS

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ABSTRACT

Hydraulic hoses are key components used to transfer power in heavy industrial machinery. The routing of these hoses is currently performed late in the product design process because no accurate physical models of the hoses exist that allow designers to predict the path the hoses will follow when installed in the machine. Designers must either guess the path the hose will take based on prior experience or wait until the first product prototype is built in order to experiment with the hose routes. This paper describes the use of ADAMS, a commercially available dynamic modeling package, to predict hose paths. The hose path model was verified by comparing the predicted paths to the paths of real hoses.

INTRODUCTION

Hydraulic hoses, which are used to transport high-pressure hydraulic fluid, are key components in many large industrial vehicles. A typical industrial backhoe machine contains approximately 100 individual hoses. These hoses are routed around and through structural components of the backhoe and present a challenge to product designers. The hoses vary in stiffness from almost rigid to very flexible and change shape when pressurized. Incorrectly designed hose routes can result in hoses that rub causing failure. When designing such a vehicle, designers must determine the hose routes and specify the hose lengths for part manufacture.

Currently, designers use CAD programs and rely on past experience to plan hose routes. Hose specialists work with product designers to plan the hose routes and allow sufficient space for the hoses in a new vehicle. The hose routes are drawn into the CAD assemblies based on the hose specialists'

knowledge of the hoses' minimum bend radii and flexibility. Later, during the prototype build, the hose lengths are adjusted using a cut-to-fit approach. Typically, one-fourth to one-third of the hose lengths must be adjusted during the prototype build. Hose clamp locations are identified, based on past experience and convenient attachment points, and the hose lengths are measured to produce the manufacturing specifications.

Relying on past experience and the cut-to-fit approach greatly reduces the ability to integrate hose design with product design. Designers generally leave 'enough room' for hoses and hose specialists must route hoses through the space that is set aside for the hoses. Our approach models the physical paths of the hoses so that the paths can be accurately predetermined without relying on cut-to-fit. This allows the designers to design areas for hose routes as they are designing the product and allows accurate hose specifications to be determined before the first prototypes. This will result in better designs, less hose failures, and faster time-to-market for the product.

This paper presents the development of a hose model for predicting the shape of hydraulic hoses. The ADAMS [1] dynamic simulation software is used to calculate the predicted hose shape and a C⁺ software program provides a pre- and post-processing interface. The hose model was verified by comparing the output from the model with the path of a real hose.

SUMMARY OF RELATED WORK

Several commercial CAD packages offer special modules for the design of hose routes. For example, SDRC offers an I-DEAS module for the design of wiring harnesses, cables, and

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hoses called I-DEAS Harness Design™. Parametric Technology provides a Pro/Engineer module called Pro/Piping. These packages allow the hose route to be easily drawn in the CAD environment and make the specification of hose ends convenient but do not take into account hose properties such as weight, axial stiffness, torsional stiffness, or bending stiffness. Because of this, a hose path designed with these tools may not take the same path as a physical hose.

Andrew Elliott [2] used ADAMS to model brake hoses and more recently, Rodriguez and Keil [3] published a methodology that also employs ADAMS to model hoses. ADAMS is a multi-purpose mechanical simulation program sold by Mechanical Dynamics, Incorporated [1]. The previous ADAMS hose models were only developed to model hoses whose paths are initially straight lines. The hose model presented here includes the ability to model complex hose paths. In order to conveniently model these paths through industrial machines, a pre- and post-processor for ADAMS was developed.

HOSE MODELING PROGRAM OVERVIEW

ADAMS is a general-purpose simulation package. An ADAMS model may be built either by using the graphical user interface called ADAMS View, or by creating a batch process. Batch processing is performed using the ADAMS Solver module. It would be time consuming to create complex hoses in ADAMS View, so a separate C++ program was written in order to conveniently pre- and post-process data to be used by ADAMS Solver. This hose-modeling program will be referred to as C_Hose. Figure 1 shows the organization of the C_Hose program.

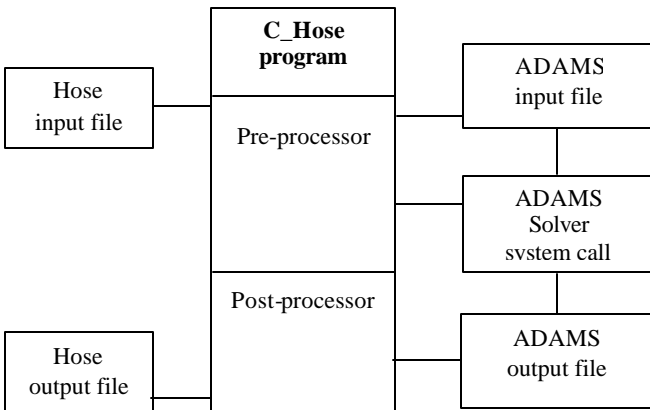


Figure 1. Flowchart of the C_Hose program

USE OF HOSE-MODELING PROGRAM: C_HOSE

A user of C_Hose starts with an initial guess for the path a hose might take through the machine. The user describes this path to C_Hose by creating an input file that lists the x -, y -, and z -coordinates of points along the initial hose path from start to end. The initial path may be designed using any CAD package or other design tool. The user also inputs the properties of the hose and which hose points are clamped. After this information is provided, C_Hose calculates the "true" path a hose of that length would take using ADAMS Solver. The "true" path of a hose is the path a real, physical hose with

the same length and properties would take under the same clamping conditions. This path is then returned to the hose designer who considers if the hose route needs to be modified.

Figure 2 shows a hose path as specified in the C_Hose pre-processor (Fig. 2(a)) and the final hose shape as calculated by ADAMS Solver (Fig. 2(b)). The hose in the figure has fixed ends, no clamps, and lies in the x - y plane with gravity acting on the hose in the negative y direction. The output of C_Hose is the positions of the points along the hose shown as large dots in Fig. 2(b).

INPUT TO HOSE-MODELING PROGRAM: C_HOSE

The input to C_Hose is a file containing a description of the initial hose path, hose properties, and clamping constraints. The initial hose path is described by a list of hose point coordinates, starting at one end of the hose and proceeding to the other. Hose points are illustrated in Fig. 2 as large dots. Also included in the input file are the physical properties of the hose, the percent change in length, and the locations of any clamps on the hose.

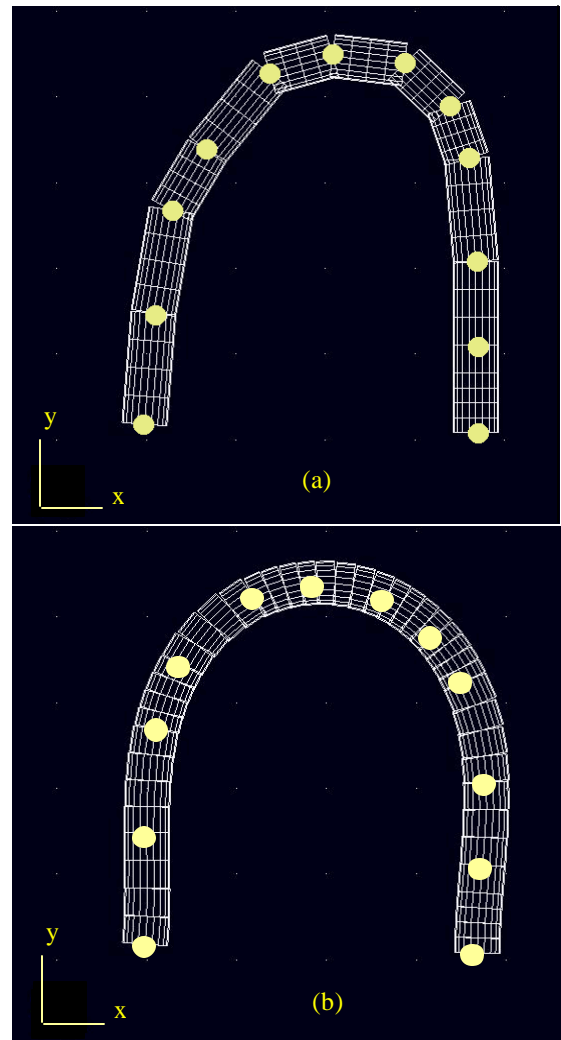


Figure 2. Example input (a) and output (b) from hose-modeling program.

The required physical properties of the hose include its weight per unit length, inside diameter, outside diameter, axial stiffness, torsional stiffness, and bending stiffness. Percent change in length is the amount that the user wants the hose to shrink or expand from its original length. This property is used primarily for modeling pressurized hoses because most hoses change in length when they are pressurized. The properties of a hose are not typically available from hose manufacturers so they must be determined experimentally. See Chipperfield and Vance [4] for a description of hose testing methods.

Clamps give the user the ability to lock the position of the input hose points. A clamp is specified at a hose point if the hose must pass through that point. For example, a clamp would be used at a point in the route where the hose must be threaded through a hole in a machine frame. Clamps are often used to keep hoses from rubbing other components in the machine while in service, which greatly reduces the life of the hose and leads to hose failures.

C_HOSE PREPROCESSOR

The pre-processor part of C_Hose reads the hose input file and builds a model of the hose in ADAMS command language. The pre-processor creates point masses along the hose at each input point and connects the masses with beam elements. The beam elements contain the stiffness properties of the hose and the mass of the hose. The mass for each beam element is calculated by dividing the total hose mass by the number of beam elements. If there is a change in length specified, the starting length of the beam elements are defined to be longer or shorter than the actual distance between the point masses. This will cause the hose to expand or shrink the desired amount when the ADAMS Solver simulation is executed. If there is a clamp defined at any of the input points, the position of the point mass at that point is constrained. This ADAMS model of the hose is written to a file that is read into ADAMS Solver during the simulation step.

In order to approximate the initial path of the hose, the pre-processor assumes that adjacent hose points in the input file are connected by straight sections of hose called hose sections. Figure 3 gives an illustration of the straight hose sections between each hose point. The hose points at the start and end of the entire initial hose path are called end points. Interior hose points include the set of all hose points except for the two end points.

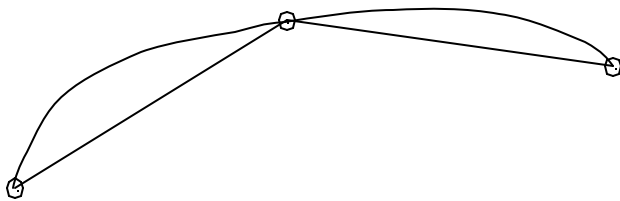


Figure 3. An initial hose path divided into two hose sections.

The next step after reading in the input information is to define ADAMS markers along each of the straight hose sections. A marker is a local coordinate system that is defined by its origin position and orientation with respect to the global

coordinate system. Usually there would be two markers per hose section (one at each end) but C_Hose allows each straight hose section to be modeled with several equally spaced markers in order to improve the accuracy of the solution. The number of markers per hose section is specified before a hose is modeled and remains the same for all hose sections. Markers must be defined at the beginning and end of each beam segment. If the number of markers per hose section were equal to five, each hose section would be modeled as shown in Fig. 4. In this example there are four beam elements per section. Markers 1-5 are on the first hose section and markers 6-10 are on the second section. Note that two markers coincide at each interior hose point: the marker at the end of the previous hose section and the marker at the beginning of the next hose section. Only one interior hose point is illustrated in Fig. 4 because the hose shown is only composed of three hose points.

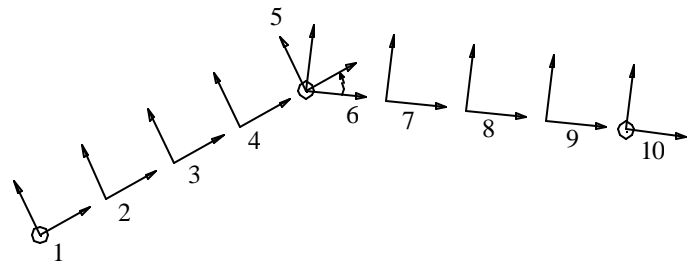


Figure 4. Placing of markers on example hose sections.

After the markers are defined for each hose section, C_Hose specifies a rotation for one of the markers at each interior hose point. Interior hose points include all hose points except for the two end points. This rotation aligns the markers at the ends of the hose sections so that tangent continuity (C^1) exists between sections. An example of a rotation can be seen in Fig. 4. In this example, marker number 6 is rotated to align with marker 5. This rotation is specified in the ADAMS input file but does not actually take place until the ADAMS Solver simulation is run. After this initial rotation aligns the markers, no more relative rotation is allowed between those two markers for the rest of the simulation, creating a C^1 continuous hose. These marker rotations are necessary so that the hose model will behave like a physical hose. Creating the hose in this manner causes it to return to straight if all clamping conditions, hose end forces, and gravitational forces are removed.

The next step is to define beam elements between adjacent markers on the same hose section. For example, in Fig. 4, beam elements connect markers 1 and 2, 2 and 3, 3 and 4, 4 and 5, 6 and 7, 7 and 8, 8 and 9, and 9 and 10. The beam element transmits forces between markers according to beam theory. It is within the beam element definition that the bending, axial, and torsional stiffness is entered. An arbitrary damping ratio of 0.1 is also included in each beam element in order to prevent the hose from oscillating during ADAMS simulation.

An additional feature of C_Hose is the ability to change the length of a hose by a percentage of its original length. This feature uses the beam element definition step to change the length of a hose in the following way. When a beam element is defined, its length must be specified along with the two end markers and the stiffness. If the specified length is equal to the

actual distance between the two markers it connects, the beam element length is in equilibrium when the ADAMS simulation starts and the total axial length of the hose will remain the same. The length of the hose is changed by specifying a beam length that is longer or shorter than the distance between the end markers. When the ADAMS simulation is run, the elements are not in equilibrium and they will change length until they reach equilibrium, therefore changing the length of the hose to the desired length.

After the beam elements are defined, C_Hose places point masses at the origin of each marker along the hose, shown as black circles in Fig. 5. The mass of each hose section (m) is calculated by multiplying the length of the section (L) by the mass per unit length for the hose. The section mass (m) is then divided up between the point masses for the section as shown in Fig. 5. The mass is divided so that there is a uniform mass distribution along the hose.

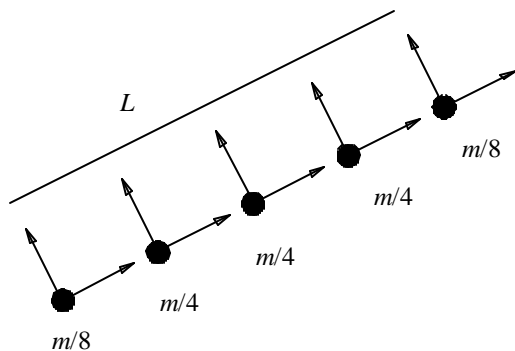


Figure 5. Distribution of mass for a hose section.

Mass moments of inertia for the hose sections are also calculated and assigned to the point masses. These moments of inertia are required for an ADAMS dynamic simulation. Two different mass moments of inertia are calculated for each hose section: 1. Mass moment of inertia for a hose with length L/j , mass m/j , and relative to a coordinate system at the center of the hose; and 2. Mass moment of inertia for a hose with length $L/2j$, mass $m/2j$, and relative to a coordinate system at the end of the hose. The variable j stands for the number of beam elements per hose section. Mass moment of inertia #1 is assigned to the interior point mass locations on the hose section and mass moment of inertia #2 is assigned to the two end point mass locations for the hose section.

The last step in the pre-processor is fixing the ends of the hose and fixing the hose at any clamp points that were specified. Both markers at the end points of the hose and any markers associated with specified clamps are locked to the global reference frame. This constraint does not allow any movement or rotation of the marker during the ADAMS simulation.

ADAMS SIMULATION AND C_HOSE POST-PROCESSOR

After the C_Hose pre-processor has created the ADAMS Solver model of the hose, an ADAMS Solver static equilibrium simulation is performed. After the simulation is executed,

ADAMS outputs the position of each hose point to a file. The hose-modeling program post-processor then reads this file, finds the final positions of each hose point, and writes these positions to an output file. This output, in the form of the (x,y,z) positions of the hose points in their equilibrium positions, is an approximation of the true path of the hose.

VERIFICATION OF HOSE MODEL

The hose-modeling program was verified for two different configurations of an example hose. The hose paths generated by ADAMS were compared with a real hose for both configurations. These tests verified the ADAMS bending model. The torsional and axial models were not verified because they are not as important as bending in hose applications. For both models, the paths ADAMS predicted were very similar to the actual paths for the real hoses.

The first test configuration was a cantilevered hose. One end of a real hose was clamped into a vise with the hose held parallel to the ground. The hose end was then released and the deflection of the free end was measured. To verify the ADAMS hose model, the hose was entered into C_Hose and the deflection of the free end due to gravity was noted. Finally, analytical expressions for the deflection of a cantilever beam were used as an additional verification method. Table 1 shows that the deflections compared favorably.

Table 1. Results of the cantilevered hose verification.

	Real hose	C_Hose model	Cantilever Beam Formula
Deflection of the free end (mm)	Approx. 50	51.3	51.75

The second test configuration was a hose initially positioned on a horizontal table (no gravity effects deflections). Using an x-y coordinate system, the hose is placed along the line $y = x$. One end of the hose was fixed at the origin and the center-point of the other end was moved in the negative y direction. The moving end of the hose was free to rotate as it moved. The deformed hose path calculated by ADAMS was plotted at full scale and the real hose was laid on top of the ADAMS hose. Figure 6 shows two pictures of the hose laid onto the drawing of the predicted path. Figure 6(a) shows the undeformed hose and Fig. 6(b) shows the same hose after it had been deformed. The real hose shown in Fig. 6 includes metal end fittings, which were not part of the model. The model only includes the black part of the real hose. The real hose took almost exactly the same path as the ADAMS model. Note that the movement of the right end of this hose required some additional modeling in ADAMS since C_Hose doesn't have the capability to model moving ends. C_Hose was used to create the model of the straight hose and that model was loaded into ADAMS View. The motion of the end of the hose was prescribed within ADAMS View and the resulting hose shape was plotted from ADAMS View. This test verified that the ADAMS beam elements, defined by the C_Hose preprocessor, modeled the hose path correctly even though the C_Hose pre-processor could not create the motion required by the test.

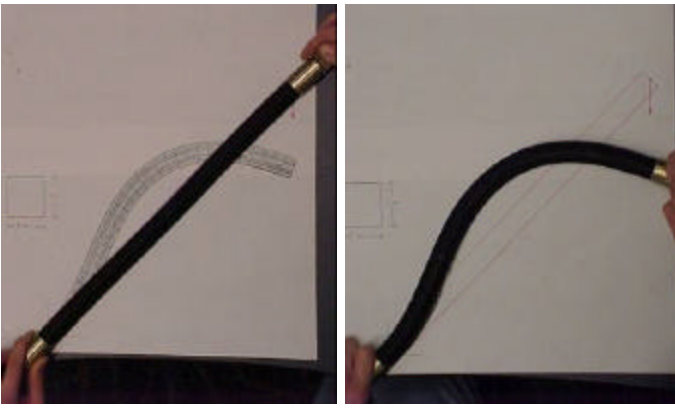


Figure 6. Real hose compared to plot of ADAMS hose model.

CONCLUSION

This paper describes a hose-modeling program that was shown to accurately model two example hoses. C_Hose requires the input of an initial hose path, clamping constraints, and hose properties. The C_Hose pre-processor uses this information to construct an ADAMS model, which is then analyzed. Finally, the C_hose post-processor creates a results file that gives the approximate path for the hose. This program

can be used by hose designers to predict the real paths of hoses before the first prototype build, allowing them to identify and correct interference problems earlier in the design process. The hose model could be improved by adding the ability to model hoses with moving end points.

ACKNOWLEDGEMENTS

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